

Issues Related to the Use of Tourniquets on the Battlefield

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On the battlefield, a properly applied tourniquet can be an extremely effective means of controlling severe extremity wound hemorrhage. However, a great deal of confusion exists among soldiers, medics, and military medical officers on a number of tourniquet-related issues. What is an appropriate combat tourniquet? When is it appropriate to use a tourniquet? When and by whom should a tourniquet be removed? Under what conditions should a tourniquet not be released or removed? What are the most effective ways to increase limb salvage while using a tourniquet? These and other issues were addressed by a panel of experts at the 2003 Advanced Technology Applications for Combat Casualty Care Conference, August 21 and 23, 2003, St. Pete Beach, Florida. Here we review those issues and present a summary of the panel's recommendations.

Introduction

Properly applied tourniquets can be an extremely effective means of controlling extremity wound hemorrhage and could prevent 7 of 100 combat deaths.^{1,2} However, tourniquet use remains controversial and is the source of a good deal of confusion.³ In civilian emergency medicine, the fear of tourniquet-related complications has all but eliminated the use of tourniquets.³ However, the Israeli Defense Forces advocate the liberal use of tourniquets,⁴ as do members of the Special Operations community.^{5,6} These divergent views have led to considerable confusion on the part of soldiers, combat lifesavers (CLSs), medics, and other military medical personnel.

A panel of physicians, medics, scientists, and biomedical engineers convened as part of the 2003 Advanced Technology Applications for Combat Casualty Care Conference, August 21 and 23, 2003, in St. Pete Beach, Florida, to address some of the major issues regarding tourniquets in combat. Care was taken to include individuals possessing combat, clinical, and/or scientific experience and knowledge of tourniquet use. We present a brief review of each issue, followed by a distillation of the panel's discussion and major recommendations, which appear in Table I.

Major Issues

What Is an Appropriate Combat Tourniquet?

Panel participants emphasized that, first and foremost, an adequate tourniquet must stop arterial bleeding; anything short of this is unacceptable. A tourniquet tight enough to occlude

venous return but not arterial flow can exacerbate bleeding. An inadequate tourniquet can also cause significant bleeding if extensive laceration of the soft tissues is present distal to the device. This is a critical point, because many soldiers, including CLSs and medics, erroneously think that partial arterial occlusion actually is preferable and will prevent limb loss from ischemia. A properly functioning tourniquet should be tightened until blood flow stops. Some oozing will continue to occur with a sufficiently tightened tourniquet because of medullary (bone) blood flow.

Tourniquet tightness must increase considerably as limb size increases. This is because of the inverse relationship between the tourniquet pressure required to occlude arterial flow and the circumference of the limb.⁷⁻¹⁰ There is also an inverse relationship between tourniquet width and the pressure required to occlude arterial flow⁸⁻¹⁰ (Fig. 1). Given that the range of limb circumferences for male soldiers are 11.5 to 15.0 inches and 20.3 to 26.7 inches for the arm and leg, respectively,¹¹ two key concepts become clear. First, complete occlusion of the leg is extremely difficult, if not impossible, with a 1-inch tourniquet, especially without mechanical augmentation (windlass, ratchet, cams, or elastic components). This is exemplified by the inability of the strap-and-buckle tourniquet (NSN 6515-00-383-0565) and the one-handed tourniquet (NSN 6515-01-504-0827), both 1 inch wide, to effectively occlude arterial flow in the leg.¹² Second, small changes in width have a large impact on reducing occlusion pressure. Thus, wider tourniquets are much more effective. However, simply increasing the width of the tourniquet strap does not eliminate the need for mechanical augmentation because, as width increases, so does the amount of tissue that must be compressed, greatly increasing the effort required to produce tension. Additionally, as the width of a strap increases the strap tends to bow, thus transmitting relatively more pressure to the center than to the edges and effectively reducing the functional width.¹³

Calkins et al.¹⁴ field-tested eight potential battlefield tourniquets. Of these, only three were capable of reliably occluding arterial flow in the lower limbs, and none of these favored one-handed operations. These included two strap/ratchet designs and one pneumatic design. These three systems were the only tourniquets tested that could augment the user's ability to tighten them by mechanical means. All others tested depended on elastic components or some form of a strap-and-buckle design. This critical observation emphasizes the fact that simple strap-and-buckle-type tourniquet systems cannot reliably occlude arterial flow in the lower limbs.

In contrast to straps, which compress limb tissue via circumferential tension, pneumatic tourniquets use inflation pressure, which is controlled more easily and more evenly applied around the circumference of the limb. Compared with strap tourniquets, the contoured pressure profile of a pneumatic tourniquet also reduces high shear stresses at the tourniquet edge that can

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TABLE I
MAJOR RECOMMENDATIONS

Replace strap and improvised tourniquets
Remove current strap-and-buckle tourniquet ^a from inventory
Candidates for replacement must undergo systematic down-selection process before consideration for inclusion in inventory
Issue suitable windlass (6–8-inch × 0.75-inch dowel or plastic tube) to all soldiers as part of hemorrhage control kit
Medics must be trained and then permitted to loosen or remove tourniquets
CLS must be trained to confidently loosen or remove tourniquets
Care under fire: use a tourniquet for any severely bleeding extremity wound
Medic: assess need for tourniquet as soon as tactical situation allows
Attempt conversion to another means of hemorrhage control
Do not remove tourniquet if
Casualty is in shock
Conversion of casualty cannot be monitored regularly for rebleeding
Tourniquet has been in place for ≥6 hours
Note time of tourniquet application on casualty's forehead.
Soldier training requires greater emphasis on tourniquet use and hemorrhage control in general, including use of bleeding manikins and sustainment training
All soldiers should be issued tourniquet and trained to use it
Pneumatic trauma tourniquet should be added to inventory and carried in all evacuation vehicles

^aNSN 6515-00-383-0565.

result in nerve damage.^{15,16} The greater width of the pneumatic tourniquet, combined with the greater effectiveness of tissue compression, also allows it to be much more effective at lower pressures, thereby reducing the likelihood of tissue damage.^{15,17} These desirable properties have nearly eliminated tourniquet-related complications after orthopedic surgery, where pneumatic tourniquets have become the standard.¹⁸ The potential advantages of a pneumatic tourniquet on the battlefield were recognized before World War II.^{19,20} However, concerns about size and weight, leaking, and ruggedness have kept them off the battlefield. These technical concerns have been largely overcome for at least one commercially available pneumatic trauma tourniquet (Delfi EMT tourniquet). The panel recognized that equipping all soldiers with pneumatic battlefield tourniquets

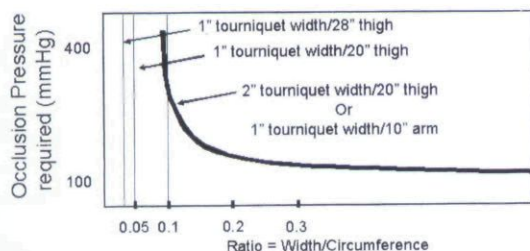


Fig. 1. Occlusion pressure vs. the ratio of tourniquet width to limb circumference.⁸ At the ratios encompassing the range of thigh circumferences representative of male soldiers, it is not possible to obtain complete occlusion with the common 1-inch tourniquet. Increasing tourniquet width has a dramatic impact on occlusion pressure. Figure 1 was reproduced from Clin Orthop (1993;286:257–61) with permission from Lippincott Williams & Wilkins.

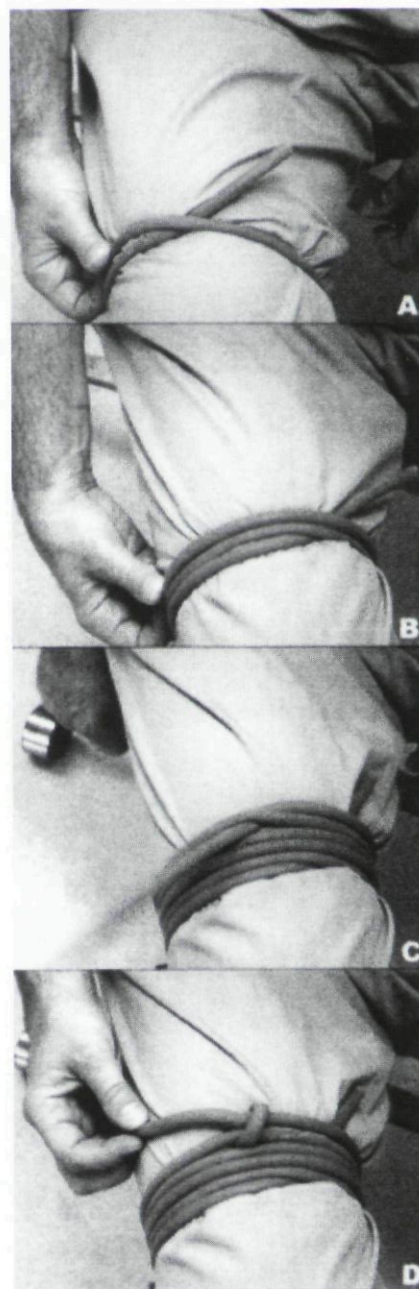


Fig. 2. Surgical tubing tourniquet, which was strongly advocated during World War II.²⁰ A 6-foot piece of 0.5-inch latex surgical tubing can provide an effective tourniquet with at least four parallel turns of the tubing around the leg (C and D). Starting 2 inches from the injury and working away, the end of the first turn is overlapped and anchored by the second turn (A) and the last turn is anchored by the next-to-last turn (B). The end can be inserted through the loop to guard against accidental release during transport. Only moderate tension is required during winding, because too much tension can be damaging to underlying tissues, as well as very painful.

might not be practical but recommended that it be considered for medics and that tourniquets be issued to all casualty evacuation vehicles.

The panel recognized the potential for the all-but-forgotten rubber tubing tourniquet, a very popular tourniquet used during World War II and first used in the 1870s. A 6-foot piece of 0.5-inch (outer diameter) latex tubing can achieve very reliable

and effective occlusion of arterial bleeding (Fig. 2).²⁰ This tourniquet has many advantages, including the ability for one-handed application to the upper arm, small size and weight, and very low cost. The disadvantage is that pressure is difficult to regulate, often resulting in excessive pressure and pain. However, the panel recommended that the rubber tubing tourniquet be considered in any future down-selection process.

Until a new, effective, battlefield tourniquet can be identified, fielded, and issued to each soldier, the improvised tourniquet or Spanish windlass remains the principal option. The Spanish windlass tourniquet (used on the battlefield since 1674), although low-tech and simple, is a reliable technique with proper instruction and practice (see Training and Education). However, because this tourniquet requires the soldier to locate a windlass, resulting in the loss of valuable time, the panel recommended that soldiers be issued a 6-inch stick or plastic tube as part of the hemorrhage control kit.

The panel agreed that the current strap-and-buckle-type tourniquet (NSN 6515-00-383-0565) needs to be removed from the inventory. This narrow tourniquet rarely controls bleeding completely and cuts into underlying skin. Although after World War II it was recommended strongly that the tourniquet be discarded,²⁰ it continues to be issued today.

The Army urgently needs an effective tourniquet system that can be carried by every soldier and is easily and rapidly self-applied.^{6,14} However, the panel voiced general concern that an emphasis on one-handed operation has overshadowed critical attention to adequate control of arterial bleeding in the lower extremities. The vast majority (68%) of injuries requiring a tourniquet occur in the lower extremities,⁴ where one-handed application is not necessary. This fact needs to be emphasized in the design of current and future battlefield tourniquets.

When Should a Tourniquet Be Applied?

Care under Fire

If a soldier is wounded under fire, then a tourniquet should be used for any severely bleeding extremity wound. While under fire, the use of direct pressure, pressure dressings, pressure points, and elevation may place the casualty and medic at additional risk of injury. Current Army doctrine supports a much more conservative approach to tourniquet use, only after all other measures have failed. However, liberal use of the tactical tourniquet has gained popular support among the Special Operations community, primarily as a result of lessons learned from such Special Operations missions as the Battle of the Black Sea in Somalia² and subsequent studies in tactical medicine.^{5,6,21}

Other Circumstances

Tourniquet use when not under fire is dictated by the inability to control bleeding by other means. The panel reiterated current policy (FM 21-11, FM 8-230, and STP 21-1-SMCT) and emphasized the need to better educate all soldiers. Additional recommendations are discussed below.

When Should a Tourniquet Be Removed?

During the early part of World War II, medical personnel briefly loosened tourniquets every 30 minutes, to allow reperfusion

TABLE II
CARE-UNDER-FIRE TOURNIQUET REMOVAL ALGORITHM

Apply hemostatic or pressure dressing to wound site
Resuscitate if needed
If casualty shows no signs of shock and no active bleeding, then loosen tourniquet and inspect wound for rebleeding
Leave loosened tourniquet in place and monitor wound frequently
If rebleeding occurs, retighten tourniquet
If tourniquet is retightened, it can be removed only by medical officer prepared to control bleeding surgically
If frequent monitoring is not possible, continue use of tourniquet, rather than risk failure to notice rebleeding
Never intermittently loosen and retighten tourniquet

sion via intact collateral circulation. As a result, death sometimes occurred from the cumulative effects of the bleeding. This led to a policy reversal in the later part of the war, giving rise to the current belief that a tourniquet should not be loosened or removed except by a medical officer.²⁰ Clearly, if more liberal application of tourniquets is advocated, then we must also adopt new guidelines for removal, to avoid unnecessary loss of limbs or even life. Regardless of the conditions under which a tourniquet is applied, the most effective method of limb salvage is early successful conversion of a tourniquet to a less-damaging means of hemorrhage control. The panel recommended that combat medics adhere to the algorithm described in Table II.

Under What Conditions Should a Tourniquet Not Be Removed?

Despite the panel's advocacy of a more liberal policy of tourniquet use and removal, there are clearly conditions that preclude tourniquet removal (Table III).

Limb Salvage

Based on studies in orthopedic surgery, a 2-hour time period generally is accepted as the safe limit before some level of functional loss occurs.^{3,18,22} Tourniquet application beyond 2 hours can result in progressive neuromuscular injury. However, we do not know at what point limb loss becomes inevitable. Wolff and Adkins²⁰ reported a number of tourniquet applications of 4 to 6 hours without any apparent deleterious effects. Lakstein et al.⁴ reported >90 cases of tourniquet application in the Israeli Defense Forces and found complications only after 150 minutes, none of which resulted in limb loss. However, it is critical to

TABLE III
UNDER WHAT CONDITIONS SHOULD A TOURNIQUET NOT BE REMOVED?

Shock: removal only by senior medical provider
Amputation
Uncontrollable bleeding: wounds involving arterial injury are too great to be controlled by any means
Extended periods of tourniquet application: a tourniquet applied to the leg for ≥ 6 hours without successful conversion should not be removed until casualty reaches forward surgical team or higher level of definitive surgical care
Inability to observe casualty: do not risk failure to notice rebleeding; leave tourniquet in place

limit tourniquet duration if at all possible. This means either recognizing when a tourniquet is not necessary or converting to a less-damaging means of hemorrhage control as soon as possible.

Surgeons commonly perform periodic reperfusion when using tourniquets during elective procedures, for bloodless extremity surgery. This practice significantly increases the length of safe tourniquet application and has been the basis of a good deal of scientific investigation.^{18,20,22-24} However, this strategy is incompatible with tourniquet use on the battlefield. As discussed above, Wolff and Adkins²⁰ found that an unacceptable number of soldiers died as a result of incremental exsanguinations from repeated loosening of the tourniquet, and the practice justifiably was abandoned.

Finally, cooling ischemic muscle profoundly reduces muscle injury.^{20,25-27} Even a 2°C to 3°C reduction in muscle temperature can significantly increase the return of muscle function after extended tourniquet application.^{26,28} The practice of exposing the limb, thereby exploiting cool environmental temperatures, was credited for successful limb salvages after tourniquet applications of up to 8 hours during World War II.²⁰ Therefore, the panel recommended that this practice be encouraged as part of soldier training. In addition, this practice reduces the chance of overlooking an injured soldier with a tourniquet once he or she is transferred to a higher echelon of care.

Training and Education

Improvements in hemorrhage control will not occur without changes in current soldier education and training at all levels.

Soldier Training

Most battlefield first aid initially is rendered by a nonmedic comrade. The panel agreed that current training in hemorrhage-control techniques, including tourniquet use, is extremely deficient. Hemorrhage-control techniques and the use of tourniquets already are common tasks taught to all soldiers upon initial entry training. However, a recent study of ~40 advanced individual training students who had completed initial entry (basic) training showed that less than one-half could recognize and treat a life-threatening hemorrhage of the thigh in a simulated patient (R.L. Mabry, unpublished observations). In addition to greater emphasis on the control of life-threatening extremity hemorrhage during basic and advanced individual training, soldiers need sustainment training, with additional emphasis on this skill during common task training and other training opportunities where field skills are emphasized, such as the Ranger course, primary leadership development course, and advanced and basic noncommissioned officer courses. This skill also should be added to the tasks tested for the Expert Field Medical Badge and the Expert Infantry Badge. Innovative training aids such as hemorrhage simulators and interactive patient manikins should be evaluated as adjuncts to improve training throughout the Armed Forces.

CLS

The CLS is a nonmedical soldier trained to provide immediate emergency care to fellow soldiers as a secondary mission when the tactical situation permits. Each squad, crew, or equivalent-

sized unit has at least one member trained as a CLS.²⁹ The panel agreed that additional training in hemorrhage-control techniques, including tourniquet use, is warranted. Training should be extensive enough for the CLS to be able to evaluate the need for a tourniquet or the suitability of a wound for another form of (less-damaging) hemorrhage control. It was the panel's opinion that this training could be accomplished within the current time constraints of CLS training if the training time for establishing intravenous access was reduced or eliminated. Current tactical combat casualty care guidelines question the utility of early intravenous fluid therapy in the field. Rapid control and arrest of life-threatening hemorrhage are more beneficial and take less time and skill than establishing intravenous access and giving fluids for resuscitation. Furthermore, it is unlikely that the small amounts of intravenous fluids available to the CLS are of much benefit, and they may even be detrimental to casualties with significant hemorrhage.

Medic

In addition to knowing how to apply tourniquets, medics should be taught under what circumstances tourniquets should and can be removed. Simple guidelines should be taught, taking into account evacuation time, the tactical situation, and the presence or absence of shock. The recommendations made by this panel would allow medics to judge when to remove unnecessary tourniquets to prevent further injury, while safely treating those casualties who need them.

Testing and Selection of Battlefield Tourniquet Systems

The panel advocated that a systematic testing process be developed and adopted, by which all potential battlefield tourniquet systems would be tested before their inclusion in the inventory. This process is critical to avoid fielding an ineffective battlefield tourniquet, as occurred in the case of the one-handed tourniquet. The process developed by the panel is similar to that of Calkins et al.¹⁴ Time did not allow the panel to develop the details of the testing process; general recommendations were made and agreed upon. Scores will be assigned to objective measures determined at each phase. Each score will be entered into a matrix, ultimately leading to the final selection.

Phase 1: Adherence to Sound Principles of Tourniquet Design

Initial consideration of any tourniquet will be based on established scientific facts and principles of tourniquet engineering (e.g., ≤1-inch width or no mechanical augmentation will not be considered). This will allow quick rejection of tourniquets outright, without further testing.

Phase 2: Laboratory Testing among Human Volunteers

Lower Limb

Once a tourniquet has passed phase 1, it will be tested on the extremities among human volunteers. Two endpoints will be determined, i.e., elimination of pulse in the posterior tibial artery, as determined by Doppler auscultation, and elimination of palpable peripheral pulse. Based on a recent study by Wenke et

al.,¹² these determinations can be made in ≤ 30 seconds. Confirmation of complete occlusion must be demonstrated before further consideration.

Upper Limb

Candidates that occlude leg blood flow will then be tested on the upper limb. This is to ensure that the device does not possess physical constraints that preclude effective use on small limbs.

Phase 3: Field Testing

Tourniquets that meet phase 2 requirements will be field tested by medics under environmental conditions similar to those encountered on the battlefield. Time did not permit the development of the details for field testing. The panel recommended that the details of this phase could be developed by the Army Medical Department Board and would involve soldiers, marines, and Special Operations Forces in various tactically relevant environments.

Phase 4: Safety Testing

In phase 4, the effective circumferential force will be determined in instrumented limb surrogates, to determine the relationship between circumferential force and occlusion pressure. This phase is designed to ensure that the potential for tourniquet injury is factored into the selection matrix, i.e., the lower the effective circumferential force, the better the score.

Phase 5: Practical Considerations

All tourniquets that reach this point will be judged on such additional considerations such as size, weight, shelf-life, ruggedness, ease of application, and cost.

Panelists

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Dr. Thomas Walters, currently at the U.S. Army Institute of Surgical Research (USAISR) as a member of the Combat Casualty Care Research Program, is a research scientist with a background in muscle physiology. Dr. Walters received his Master of Science degree in exercise physiology and his doctorate in muscle physiology from the University of Texas at Austin. From 1990 to 2000, he performed research at Brooks Air Force Base, Texas, in thermal stress and its role in limiting physical performance. His current research focuses on issues related to extremity trauma, including tourniquet-related injury.

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Dr. Robert Mosebar is a medical consultant for the Directorate of Combat and Doctrine Development, U.S. Army Medical Department Center and School (Fort Sam Houston, Texas). His military career spans >50 years and has ranged from a combat medical aidman and litter-bearer during World War II to numerous medical commands until his retirement in 1996. Dr. Mosebar introduced the concept of the CLS for the battlefield to the Army.

Robert Pedowitz, PhD MD

Dr. Robert Pedowitz is an associate professor in the Department of Orthopedics at the University of California, San Diego. He is the chief of Sports Medicine and the program director for the University of California, San Diego, Orthopedic Surgery Residency Training Program. Dr. Pedowitz completed medical school and residency at the University of California, San Diego, and completed a sports medicine fellowship at Duke University. His doctorate was awarded by the University of Gothenburg (Gothenburg, Sweden) for a thesis titled "Tourniquet-Induced Neuromuscular Injury," and he has published 16 scientific articles on tourniquet-related injury.

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Kevin Inkpen received the Bachelor of Engineering degree from Lakehead University (Thunder Bay, Ontario, Canada) in 1997 and the Master of Applied Science degree from the University of British Columbia in 1999, both in Mechanical Engineering. He is currently working as a development engineer in Vancouver, British Columbia, Canada, for Delfi Medical Innovations, which develops and manufactures surgical and specialty tourniquet products.

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SFC (Ret) Robert Miller

Robert Miller is currently the chief executive officer of Innovative Casualty Response and the program director for North American Rescue Products. He serves on the Committee on Tactical Combat Casualty Care and is an editorial consultant for the *Journal of Special Operations Medicine*. Mr. Miller holds a bachelor's degree in Health Sciences and recently retired from the Ranger Regiment with 20 years of experience as a Special Operations combat medic. He was the primary developer of "Ranger First Responder," a war-fighter combat trauma training course that has replaced the U.S. Army CLS course in several units within the Special Operations Command.

SFC David Funk

SFC David Funk is a Special Forces 18D medic assigned to U.S. Special Operations Command. He is a founding member of the 3rd Ranger Battalion. Before his current assignment, he spent 10 years assigned to the 7th Special Forces Group. He received his medic training in 1995. SFC Funk is also a dive medical technician and hyperbaric chamber operator.

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